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Project Code Number 7300

Order Number 306-62

LASER MATERIAL STUDY

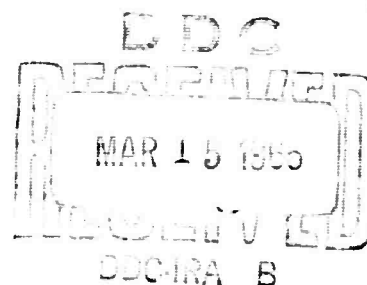
Final Report

22 February 1965

By
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ABSTRACT

A critical comparison of three types of neodymium doped laser glass has been conducted. The glasses were chosen because of their widely differing fluorescence characteristics. The three consisted of a lanthanum-barium borate, a lithium-sodium silicate, and a barium crown.

The glasses were fabricated into rods, 1.27 cm diameter and 30.5 cm long. Fluorescence decay data, optical quality data, output-input data and output field patterns, are included in the report.

The fluorescence characteristics were less significant than optical quality as a determinant in laser behavior.

This work concludes contract Nonr-3834(00) Order Number 306-62, Project Code Number 7300. Reference should be made to the four previous semi-annual technical reports, covering the period July 1, 1962 to June 30, 1964.

Key Words

Laser, Neodymium, Glass, Efficiency, Coherence

INTRODUCTION

The bulk of the Eastman Kodak effort under this contract was conducted between July 1962 and June 1963. During this period a multiplicity of glasses and several different rare earth dopings were evaluated for potential laser performance. A modification of one of our rare earth borate optical glasses, designated ND-10, was made available commercially in finished rod form in the fall of 1962. A lithium silicate developed entirely as a result of the contract has since been introduced as a commercial product under the designation ND-11. In addition, ytterbium doped borate, YB-20, whose development has been partially funded by this contract, is now commercially available.

A technique has been developed under this contract for experimentally determining the amplification coefficient of excited neodymium doped glass. This work was published as a letter to the editor of APPLIED OPTICS, in March 1964.

This report contains the final data obtained on three laser rods of similar geometry and absorption but with differing fluorescence lifetimes.

SECTION 1

GLASS DESCRIPTION

The terminal effort of this contract has been to evaluate the laser performance of three glass compositions. These compositions have been chosen by virtue of their different capabilities in influencing the fluorescence properties of the active neodymium doping ions. A description of these three compositions follows:

I. Borate - A simple ternary composition consisting of barium, lanthanum, and boric oxides. Glasses in this system are characterized by modest thermal expansion, very low viscosity at high temperatures, and a limited working range. The dominant structural unit is a boron atom surrounded by either three or four oxygen atoms. The three coordinated boron has a higher frequency infrared absorption, and may be responsible for the capability of borate glasses to "quench" neodymium fluorescence. This "quenching" in a high boric oxide glass amounts to about 80%, i.e., the total fluorescence output is 20% or less of that of a comparably excited pure silicate glass.

II. Lithium Silicate - A composition of pure silica glass with large amounts of lithium and sodium oxides as modifiers, together with some barium, strontium, and lanthanum oxides to complicate the structure and to improve the glass forming properties. The thermal expansion is relatively high, the viscosity is low at high temperatures, and the slope of the viscosity-temperature curve is less than that of the borate, resulting in a lower annealing temperature. The incorporation of large amounts of lithium tends to polarize the oxygen ions in the glass which in turn exert asymmetric fields on the neodymium doping ions. These asymmetric fields allow relaxation of the selection rules which forbid radiative transitions between the neodymium energy levels. The result is a comparatively short fluorescence lifetime, and a high fluorescence efficiency. The high fluorescence efficiency is related also to the lack of components in the glass which have high frequency phonon modes capable of draining off the energy stored in neodymium.

III. Barium Crown - A silicate glass incorporating primarily potassium and barium modifiers with a high molar proportion of silica. The large potassium and barium ions do not have a strong polarizing effect on the oxygen in the glass, consequently the ligand field of the neodymium ions is weaker and more symmetrical. The long fluorescence lifetime observed results from this symmetry. Due to the high silica content, this glass has high viscosity at high temperatures. This makes it difficult to properly stir the ingredients during the manufacture of the glass, resulting in an inhomogeneous index of refraction.

In the fabrication of all these glasses, an effort has been made to use the purest commercially available chemicals, particularly with regard to iron. The borate glass has the highest purity in this respect since high purity boric oxide is readily available. Our estimate of total iron content in the borate is less than 2 parts per million. Both silicates, however, contain about 20 parts per million

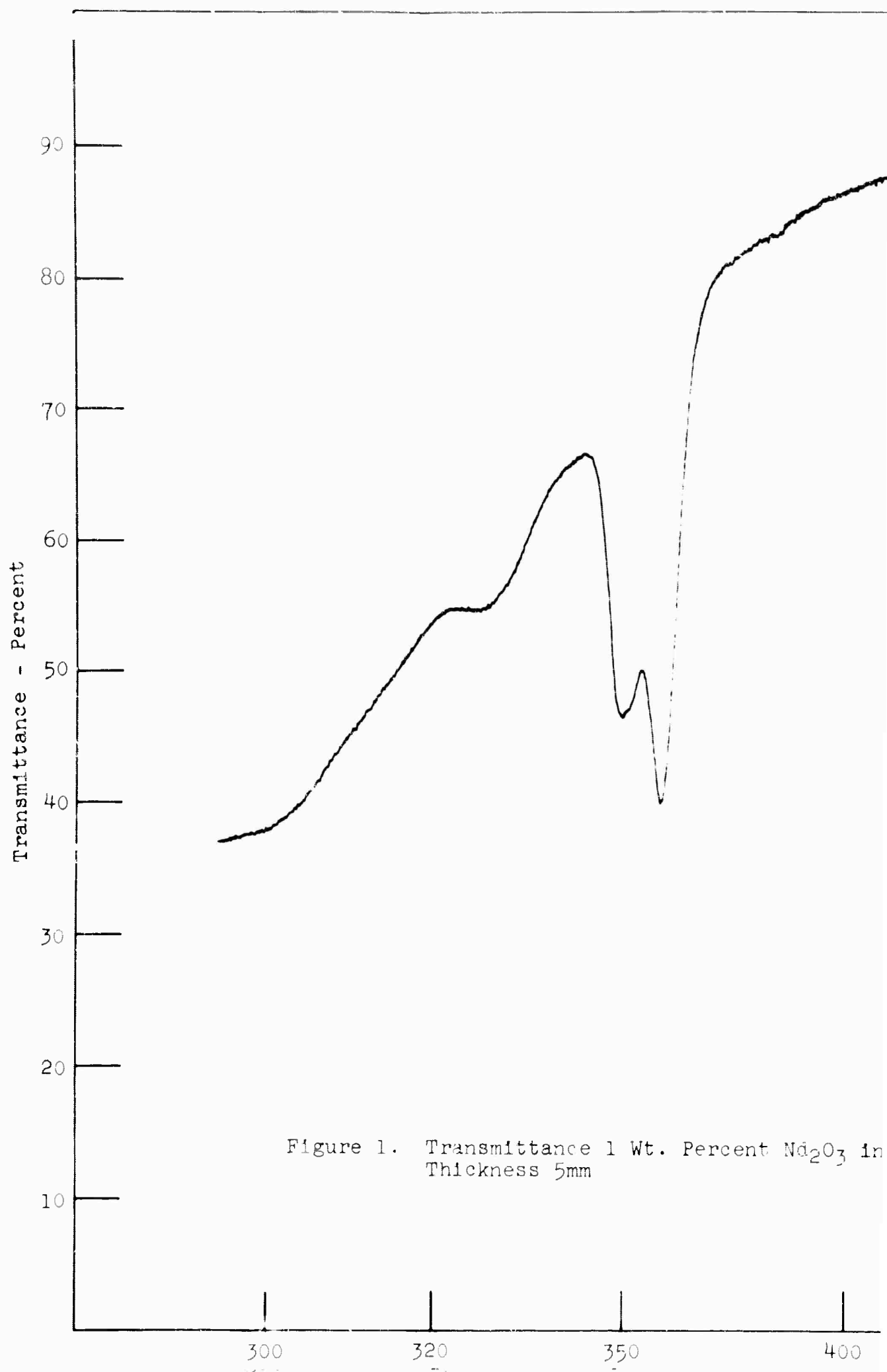
iron, due to the difficulty of obtaining high purity silica. Since the test samples evaluated in this report were made, we have been able to significantly reduce the iron content of silica, so that our commercial silicate laser glass is somewhat better in this regard.

Table 1 lists some chemical and physical characteristics of these glasses, where known. The barium crown was made for our use by an outside vendor, so many of its properties are unavailable. Absorption spectra for 5 millimeter thicknesses of the three glasses are presented in Figures 1, 2, and 3. Although the various absorption lines vary in relative intensity, the total absorption for the three glasses is quite comparable. It should be noted that to achieve this, it was necessary to use twice the weight percentage of neodymium in the barium crown as in the other two formulations.

Figure 4 indicates the relative optical quality of the three glasses tested. A 6328A^o gas laser interferometer produced the fringes which represent interference between light reflected from one end of the rod, and that which is transmitted by the rod, reflected by the other end, and transmitted back through the rod to the front surface. The fringes observed in the borate and lithium silicate were deliberately introduced by bending the rods. Those in the barium crown are difficult to see clearly due to the pronounced striae in the glass. The fine fringes are instrumental and should be disregarded.

TABLE 1

Composition (wt %)	Borate	Ld-Silicate	Barium-Crown
	La_2O_3 12, BaO 35,	Li_2O_3 1, Na_2O 10,	Nd_2O_3 2
	B_2O_3 45, Nd_2O_3 1	BaO 10, SrO 10,	
		La_2O_3 12, SiO_2 50	
		Nd_2O_3 1	
Density (gms/cc)	3.707	3.089	2.877
Refractive Index 1.06 μ	1.6444	1.5801	1.5276
Thermal Expansion ($10^{-6} \text{ } ^\circ\text{C}^{-1}$) 25 $^\circ\text{C}$ - 125 $^\circ\text{C}$	6.7	10.8	-
Absorption Coefficient (cm^{-1}) 800 m μ 583 m μ	2.6 3.8	2.1 2.7	1.6 4.4
Absorption Cross Section (10^{-20} cm^2) per ion-800 m μ per ion-583 m μ	1.9 2.9	1.9 2.4	0.77 2.1
Littleton Points ($^\circ\text{C}$) Softening Anneal Strain	683 611 602	55 433 415	
Lifetime (μ sec)	51	360	755
Absorption Coefficient (cm^{-1}) 1.06 μ	.0015	.0023	0.0048





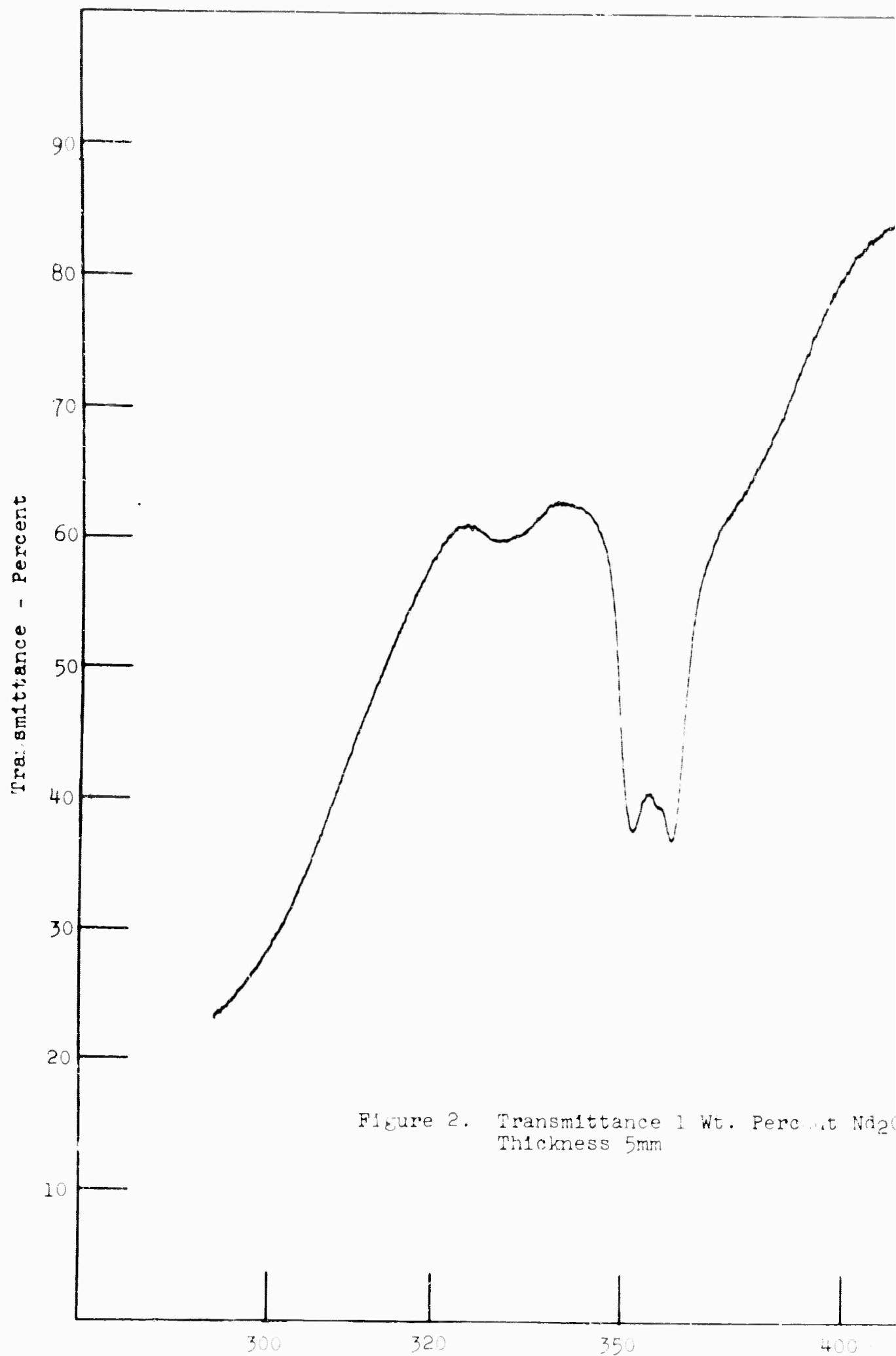
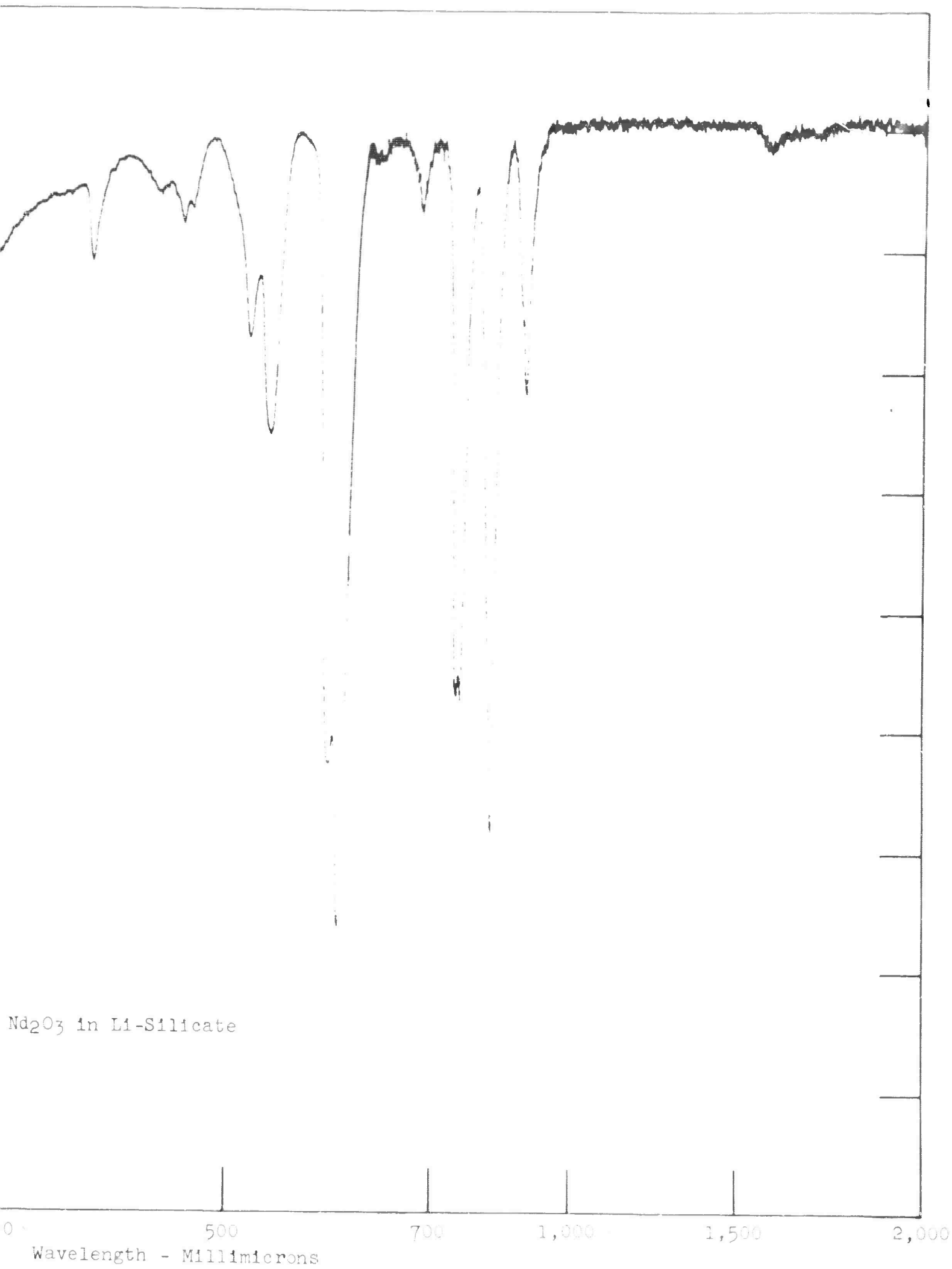


Figure 2. Transmittance 1 Wt. Percent Nd_2O_3
Thickness 5mm



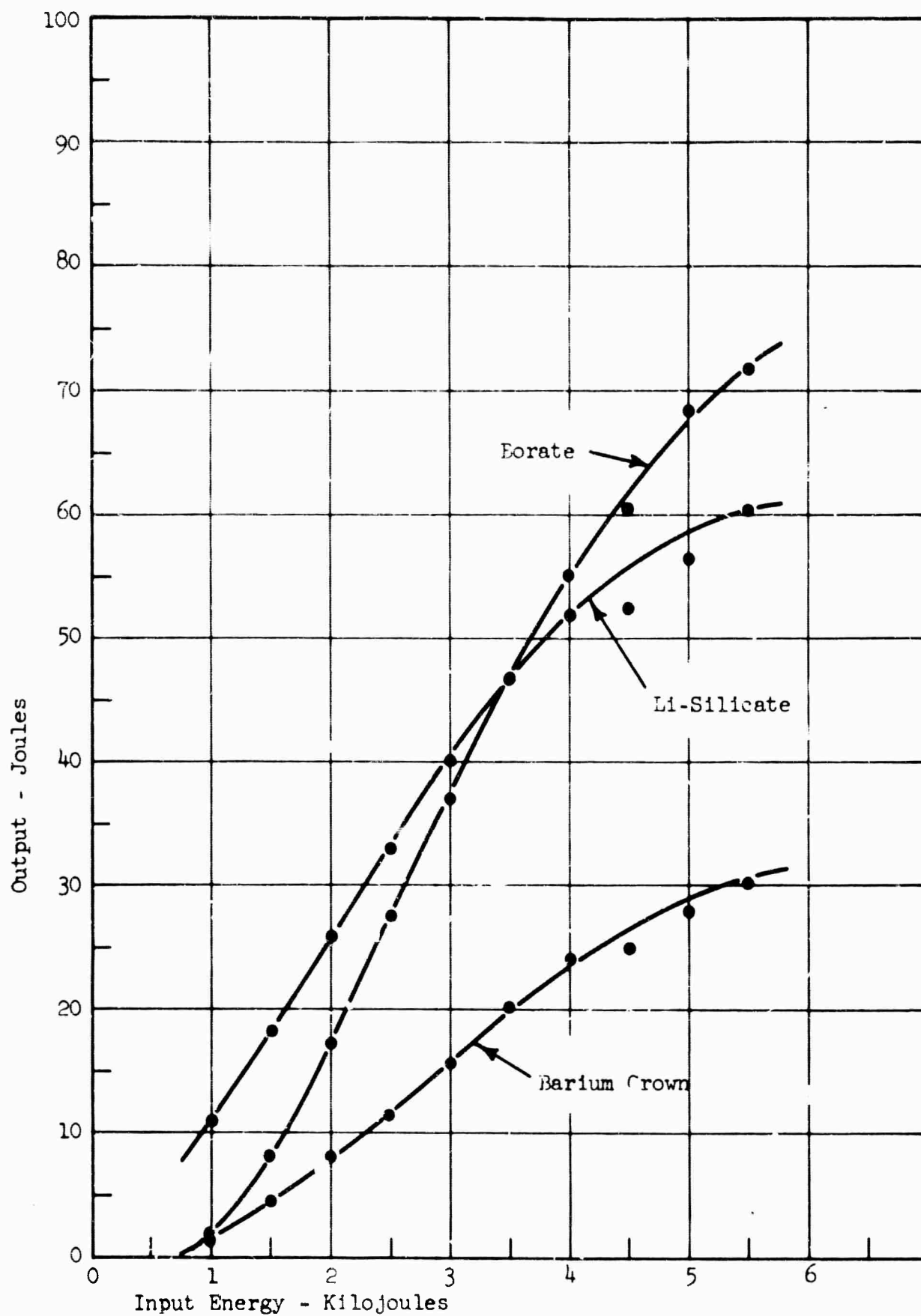


Figure 9. Laser Output as Function of Electrical Input to Flashtube. Output Mirror Reflectance 70%

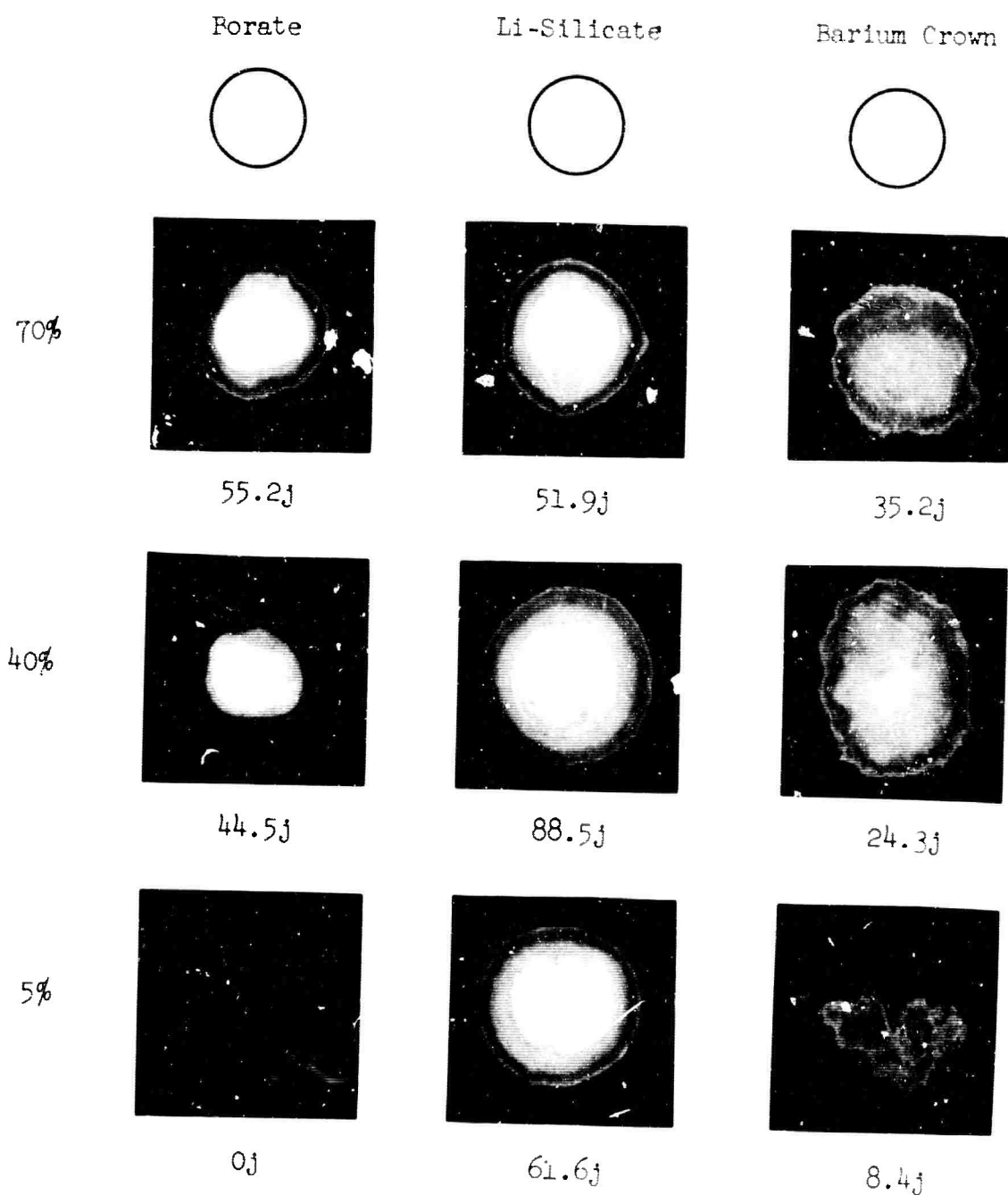


Figure 10. Field patterns recorded 288cm from output mirror of laser cavity. Input energy for each case was 4000 joules. Circles above patterns represent laser rod diameter. Numbers below each pattern indicate output joules recorded.

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